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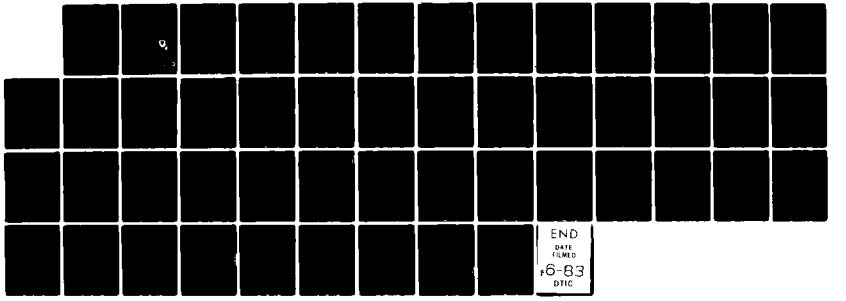

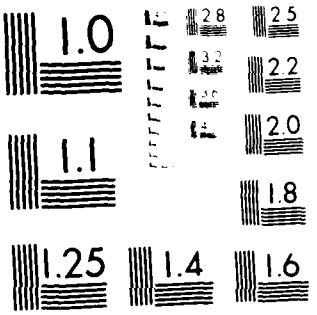

HDL-SR-83-2
March 1983

A Catalog of Fluidic C-Format Laminates

by James W. Joyce

U.S. Army Electronics Research
and Development Command
Harry Diamond Laboratories
Adelphi, MD 20783

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Harry Diamond Laboratories has recently adopted a standard format—designated "C format"—for fluidic laminates. This format permits optimal flexibility within its 1.3 × 1.3 in. (3.3 × 3.3-cm) area, and produces a vertical stack of horizontally laminated elements to build up fluidic circuits.

This report catalogs C-format laminates. These laminates have been initially categorized according to their general functions; within each such category, each individual laminate configuration is then pictured and its specific functions are discussed. (Cont'd)

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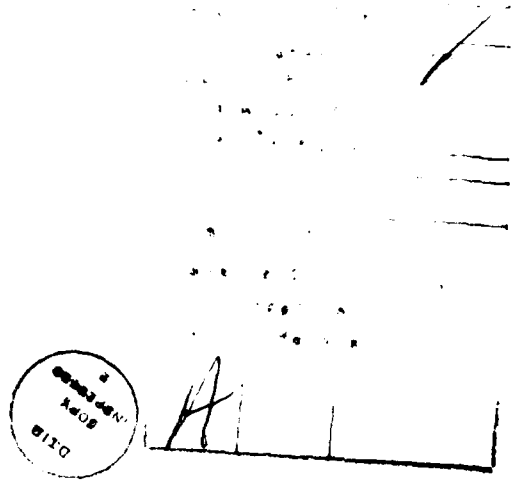
20 Abstract (Cont'd)

Although some 79 laminates are presented herein, this catalog will be expanded on a continuing basis as new configurations are designed, fabricated, and put into general use

FOREWORD

This catalog of C-format laminates is intended to be used in combination with another report, entitled Design Guide for Laminar Flow Fluidic Amplifiers and Sensors, HDL-CR-82-288-1 (April 1982). These two reports together will serve as a handbook to assist engineers in the design and assembly of fluidic circuits for controls applications.

The catalog has been designed for the reader's convenience. In each section we present the various configurations of C-format laminates that have so far been designed and fabricated, along with some general comments regarding their use. At the end of each section is a blank page for notes. The binding of the catalog was chosen so that readers can easily add pages as more laminates are designed and inventoried.



CONTENTS

FIGURES

1. INTRODUCTION

The Harry Diamond Laboratories (HDL) has recently adopted a standard format—designated "C format"—for fluidic laminates. This format permits optimal flexibility within its 1.3- × 1.3-in.* area, and results in a vertical stack of horizontally laminated elements to build up fluidic circuits. The C format can accommodate fluidic laminar proportional amplifiers (LPA's) with a supply nozzle width (b_s) of up to 0.030 in. Vertical stacking minimizes interconnection distances and volumes and thereby minimizes the signal losses, parasitic impedances and probability of leaks.

This format was adopted at a time when virtually all research and development work at HDL (and generally within other parts of the government) involved the use of laminar-flow (second-generation) components rather than the turbulent-flow (first-generation) devices used in the early years of the technology. Consequently, the emphasis in developing the individual laminate configurations has been on second-generation fluidics, which translates into eliminating sudden turns, discontinuities, unusual shapes, or other geometries that might introduce flow noise into the fluidic circuit.

The basic C-format pattern and nomenclature are shown in figures 1 and 2. Holes A, B, C, and D (fig. 2) are generally used to get supply and vent flow into and out of the circuit, while holes 1 through 20 are used for signal transmission inputs and outputs. The four marked corner holes are used to bolt the stack together and, with the aid of 9/64-in.* diameter pins, to properly align the laminates during assembly before bonding or bolting.

A given laminate has eight possible orientations, each identified by its corresponding notch position, as shown in figure 3. Thus, using C format, any fluidic circuit can be fully defined by a specific laminate stacking order that lists each laminate and its corresponding orientation. A form of the type illustrated in figure 4 is recommended for listing the stacking order of a circuit. Some specific circuit stacking orders are contained elsewhere.[1] In addition, numerous gain block configurations using LPA's are defined in HDL-TM-82-10.[2]

In general, the types of laminates used in C format can be described by their functions, as indicated below.

(a) Active elements
(b) Exhausts
(c) Gaskets
(d) Resistors
(e) Transfers
(f) Vents
(g) Miscellaneous

The active elements are primarily fluidic amplifiers (e.g., LPA's), and are consequently the most critical items in terms of manufacturing accuracies and precision. For most uses, resistor laminates will also be fairly critical if repeatable circuit performance is to be expected from one unit to another. Most of the remaining laminates are considered to be noncritical.

In the sections that follow, the various configurations of C-format laminates that have been designed and fabricated are presented, along with some general comments regarding their use. At the end of each section is a blank page for notes. Readers are encouraged to use these pages to keep track of additional laminate configurations that they design and add to their own inventory of parts.

The amplifier and resistor laminates have been given special nomenclatures that help describe their physical or functional properties. These nomenclatures are defined at the beginning of their appropriate sections (i.e., active elements, resistors). The numbering system for the remaining laminates is arbitrary and tells nothing about their configuration or function.

*(in.) × 25.4 = (mm)

[1] M. F. Cycon and D. J. Schaffer, Design Guide for Laminar Flow Fluidic Amplifiers and Sensors, Garrett Pneumatic Systems Division report, under contract from Harry Diamond Laboratories, HDL-CR-82-288-1 (April 1982).

[2] T. M. Drzewiecki, Fluerics 42 Some Commonly Used Laminar Fluidic Gain Blocks, Harry Diamond Laboratories, HDL-TM-82-10 (September 1982).

Dimensioned drawings for all laminates presented herein are available upon request from HDL. As new configurations are created and used, they will be added to this catalog, probably in the form of semiannual or annual (based on need) addenda sheets that can be easily inserted in the basic catalog. All users of this format are encouraged to notify HDL of any new configurations that they generate so that HDL may assign the part number and add it to this catalog.

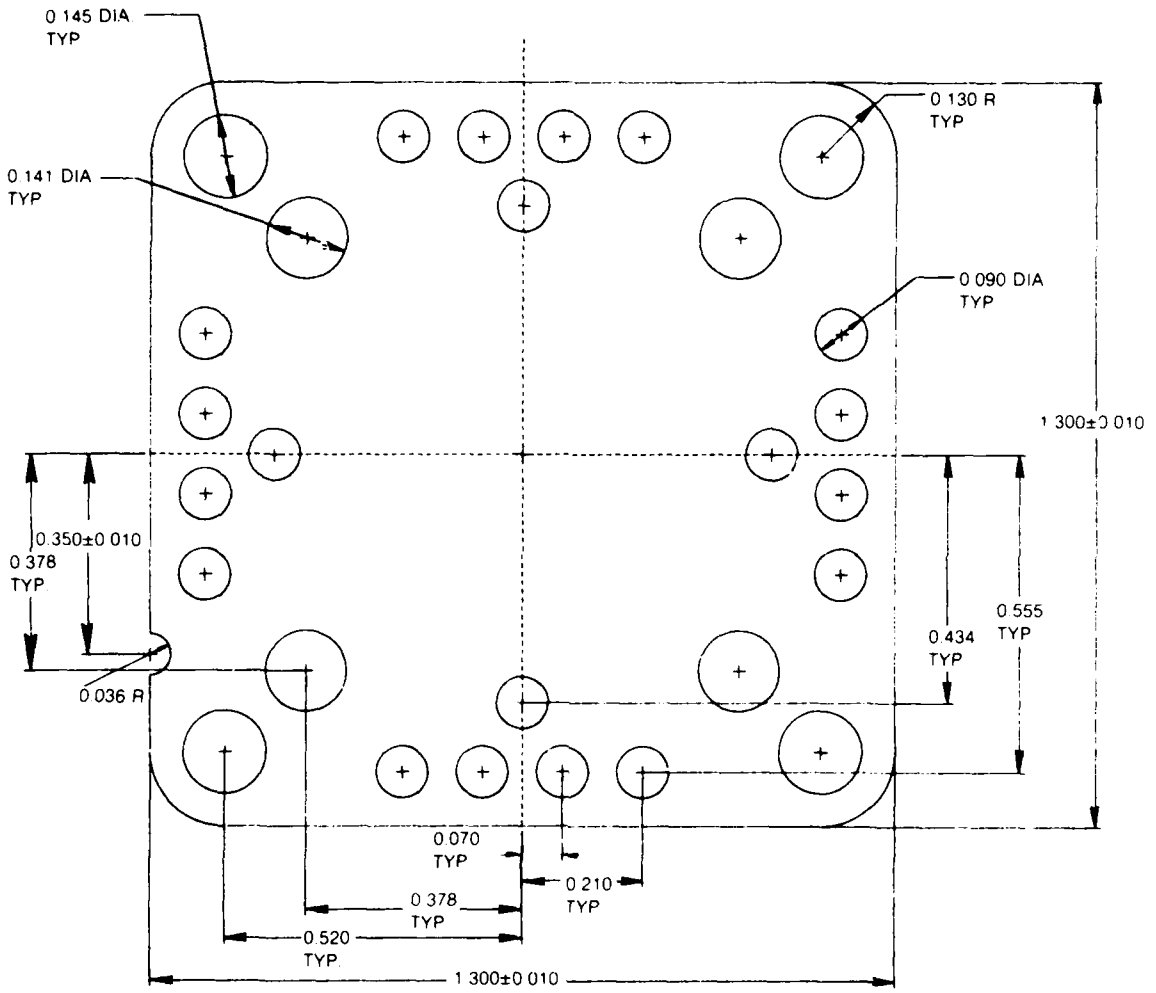


Figure 1. C format, basic pattern.

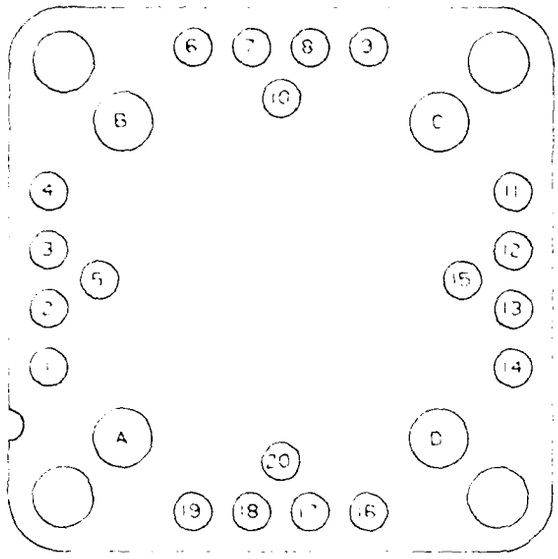


Figure 2. C-format hole nomenclature.

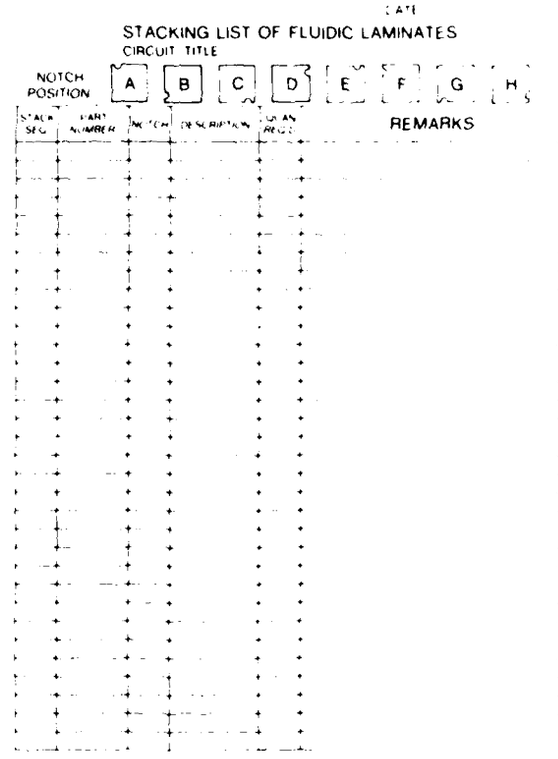


Figure 4. Stacking order sheet.

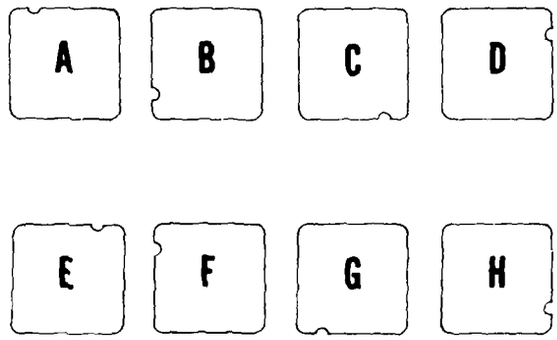


Figure 3 C-format laminate orientation identification.

2. ACTIVE ELEMENTS

The basic building block in laminar-flow fluidics is the LPA. A standard LPA configuration (HDL model 3.1.1.8) was developed by HDL and has been in use for some time now.[1] Its critical geometric parameters, normalized by supply nozzle width, are constant, so that units may be scaled to various absolute sizes. As mentioned earlier, the C format can accommodate the standard LPA with a maximum nozzle size of 0.030 in.

A special nomenclature has been developed for LPA's, to describe their size and method of fabrication. This nomenclature consists of a five-digit number, the first of which describes the fabrication method used to make the LPA, using the designations shown below.

Code	Fabrication method
5	Photochemical milling
6	Fine blanking
7	Precision stamping
8	Wire electrical discharge machining (EDM)

Detailed descriptions and pertinent attributes of these processes as they relate to the manufacture of fluidic components are contained elsewhere.[3]

The last four digits of the nomenclature identify the nozzle width and depth, in that order, expressed in 10^{-3} in. Thus, a 62010 LPA is a fine-blanked unit with a nozzle width of 0.020 in. and a depth of 0.010 in. The LPA sizes in use are pictured on the pages that follow.

Another useful active element in laminar-flow fluidics is a rectifier. The nomenclature described above is also applied to rectifiers, with the addition of the letter "R" at the end of the five-digit number. Thus, a photochemically milled rectifier with a nozzle width of 0.015 in. and a depth of 0.004 in. would be a 51504R laminate. The rectifier sizes in use are similarly pictured on the pages that follow, appearing after the LPA's.

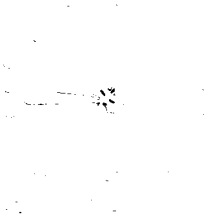
[1] *M. F. Cycon and D. J. Schaffer, Design Guide for Laminar Flow Fluidic Amplifiers and Sensors, Garrett Pneumatic Systems Division report, under contract from Harry Diamond Laboratories, HDL-CR 82-288-1 (April 1982)*

[3] *J. S. Roundy, Manufacturing Techniques for Producing High Quality Fluidic Laminates at Low Cost, AiResearch Manufacturing Company of Arizona, under contract from Naval Air Systems Command, N00019-78-C-0365 (September 1980)*

ACTIVE ELEMENTS

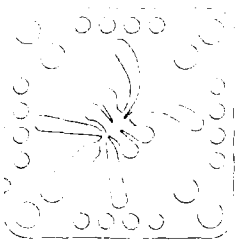
LAMINAR PROPORTIONAL AMPLIFIERS

Laminate No. 510xx
810xx



Laminate No. 515xx
615xx
815xx

Laminate No. 520xx
620xx
820xx



Laminate No. 530xx
630xx
730xx
830xx

Laminate No. 510xxR

Laminate No. 515xxR

Laminate No. 520xxR

ACTIVE ELEMENTS

SPECIAL-PURPOSE AMPLIFIERS

Laminate No. 5370A

b_S=0.020 in
X_{sp}=4
High-pressure recovery amplifier.

Laminate No. 5390A

Set point sensor for fluidic pressure regulator.

NOTES

EXHAUSTS

3. EXHAUSTS

In general, the function of exhaust laminates is to gather flows from central portions of the laminate and connect them to one or more of the power/exhaust holes (A, B, C, D, as identified in fig. 2). In some cases, these laminates will exhaust flows directly out the side of the stack through an opening in one of the outer edges.

Exhaust laminates are also used to transfer the supply pressure from one power/exhaust hole to another, as would be required in a multistage LPA gain block.

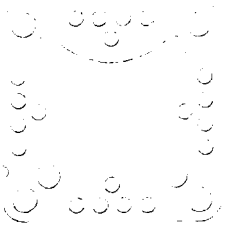
All exhaust laminates are noncritical, i.e., they do not require tight dimensional tolerances. The only somewhat tight tolerances are for the four corner holes because they must accept dowel pins, usually mounted on a base fixture, to align the stack during assembly before bonding or bolting. Exhaust laminates have been fabricated exclusively by photochemical milling. On the pages that follow in this section, all exhaust laminates in use are pictured along with their identifying numbers and brief notes, where appropriate, to describe particular common uses. As stated earlier, the laminate numbers for exhausts were assigned arbitrarily and do not indicate the laminate's use or geometry.

EXHAUSTS

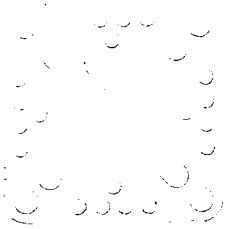
Laminate No. 5011A

Often used to transfer power supply flow from one corner to another.

Laminate No. 5062A

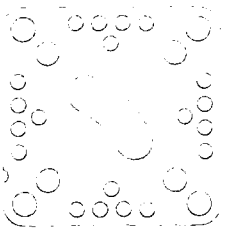


Laminate No. 5198A



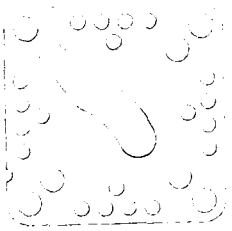
Exhausts flow through side of stack.

Laminate No. 5215A



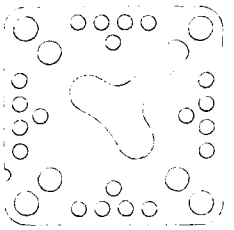
Collects vent flow from $b_S = 0.020$ in. (with vent laminate No. 5137A).

Laminate No. 5216A



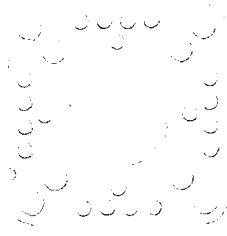
With laminate No. 5215A, routes vent flow to corner hole.

Laminate No. 5217A



With laminate No. 5215A, routes vent flow to corner hole.

Laminate No. 5237A



Collects vent flow from b_S=0.030 in. LPA (with vent laminate No. 5236A).

Laminate No. 5239A

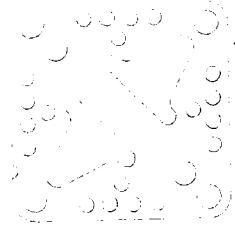
Laminate No. 5242A

Collects vent flow from b_S=0.010 in. LPA (with vent laminate No. 5241A).

Laminate No. 5340A

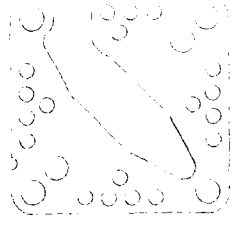
Collects vent flow from b_S=0.015 in. LPA (with vent laminate No. 5339A).

Laminate No. 5362A



Collects flow from multiple-resistor laminate (resistor laminate No. 5359A).

Laminate No. 5389A



Exhausts flow through side of stack.

NOTES

4. GASKETS

All gasket laminates are variations of the basic format shown in figure 1, with one or more holes removed. The function of the gaskets is to selectively pass pressures and flows from one part of the stack to another. At one extreme is the laminate that passes all signals (No. 5040A); i.e., holes A, B, C, D, and 1 through 20 are all present. At the other extreme is the laminate that blocks all holes (No. 5019A).

The gasket laminates, like the exhaust laminates described in the previous section, are noncritical and have been fabricated only by the photochemical milling process.

On the pages that follow in this section, all gasket laminates in use are pictured together with their identifying numbers and brief notes, where appropriate, to describe particular common uses.

GASKETS

Laminate No. 5018A

Blocks one pair of signal holes; used in staging LPA's

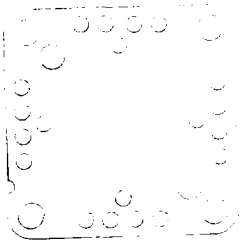
Laminate No. 5019A

Normally used as the last laminate of a stack.

Laminate No. 5021A

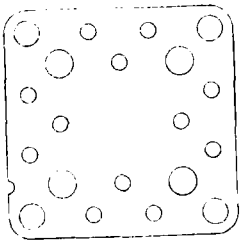
Blocks one corner hole; commonly used when transferring power supply from one corner to another.

Laminate No. 5022A



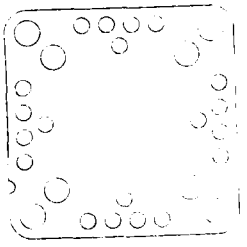
Blocks two corner holes; used to isolate power supply or vents from one stage to another.

Laminate No. 5034A



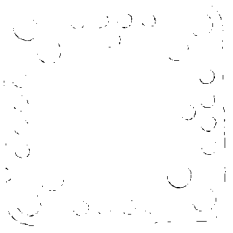
Connects to base plate hole pattern (with transfer laminate No. 5033A).

Laminate No. 5040A



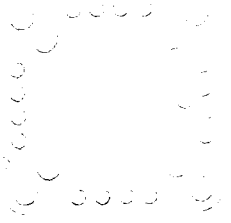
Universal gasket; connects all holes.

Laminate No. 5041A



Blocks one signal hole.

Laminate No. 5042A

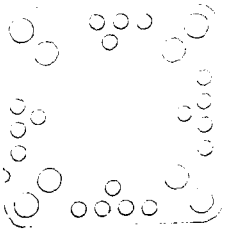


Blocks three signal holes.

Laminate No. 5043A

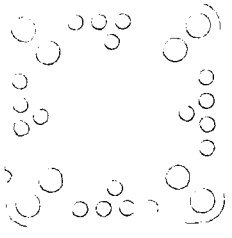
Blocks all peripheral holes.

Laminate No. 5044A



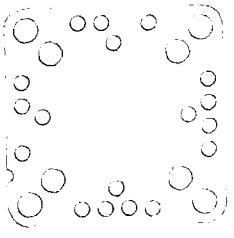
Blocks two peripheral holes.

Laminate No. 5045A



Blocks two peripheral holes

Laminate No. 5046A



Blocks two peripheral holes.

GASKETS

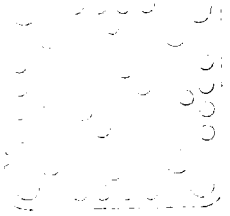
Laminate No. 5047A

Blocks two peripheral holes.

Laminate No. 5048A

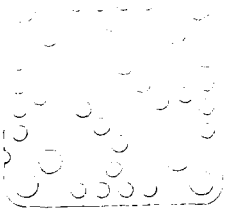
Blocks all but the four corner holes; used to isolate circuits within a stack.

Laminate No. 5357A



Permits use of two resistors in parallel (with resistor laminate No. 5359A).

Laminate No. 5358A



Permits use of three resistors in parallel (with resistor laminate No. 5359A).

Laminate No. 5361A

Permits use of four resistors in parallel (with resistor laminate No. 5359A).

NOTES

5. RESISTORS

In general, resistor laminates have two uses in fluidic circuits. Perhaps the most common of the two is to drop the supply pressure from the manifold level to values required for individual stages within a multistage gain block. The other use is for in-circuit resistors, such as a balance resistor in a bridge network.

Numerous configurations of resistors are illustrated on the pages that follow in this section. One particular configuration—the one identified as 5221A—has been used extensively and has been fabricated in different thicknesses (and in some cases, different nozzle widths) to produce a variety of resistance values. This configuration has also been made using both the photochemical milling and fine blanking processes. Consequently, a special nomenclature has been devised for these laminates, and is defined as follows. As with the amplifier laminates (sect. 2), the first digit indicates the method of fabrication, where 5 signifies chemical milling and 6 fine blanking. The initial digit is followed by the letter R (resistor) and three additional digits which identify the nominal resistance value, expressed in T/LPM, when air is the working fluid. Thus, a laminate labelled 5R225 is a photochemically milled resistor with a value of 225 T/LPM.

Experimental data have shown that the manufacturing methods cited can produce resistor laminates with corresponding resistance values that are repeatable within 3 percent for photochemically milled laminates and about 5 percent for fine blanked ones.[4]

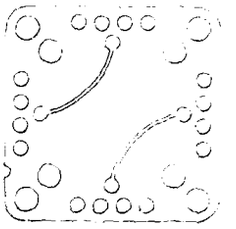
[4] J. A. Tate and O. K. Isaacs, *Final Report, Performance Evaluation of Fluidic Laminar Proportional Amplifiers, Vent Plates, and Dropping Resistors Fabricated by the Fine Blanking Process*, Garrett Pneumatic Systems Division Report No. 4-3503, July 1982.

RESISTORS

Laminate No. 5026A

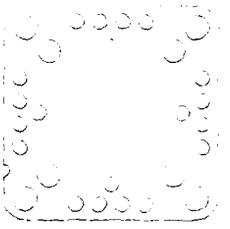
Folded capillary resistor, often used as feedback resistors in an operational amplifier. Nominal resistance of one path is about 3000 T/LPM.

Laminate No. 5027A



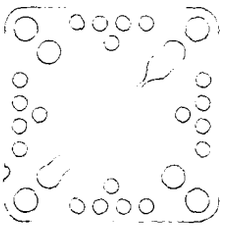
Capillary resistor with nominal resistance in one path of about 500 T/LPM.

Laminate No. 5207A



Orifice resistor; 0.030 in. diameter hole in place of normal hole No. 10.

Laminate No. 5221A



Exists in the following forms (see text for explanation of nomenclature):
5R200, 5R300, 5R500
6R035, 6R085, 6R225

Laminate No. 5359A

Multiple resistor with
the following values
available:

R_2 = 70 T/LPM (with gasket laminate No. 5357A)
R_2 = 45 T/LPM (with gasket laminate No. 5358A)
R_2 = 37 T/LPM (with gasket laminate No. 5358A)

The subscripts (i.e., 2, 3, 4) indicate the number of resistor paths used in parallel.

NOTES

6. TRANSFERS

Transfer laminates are used to connect various combinations of the C-format holes to reroute pressures and flows within the stack. One of the more common uses for these laminates is to connect one or more of the LPA input or output signals (holes 5, 10, 15, 20 in fig. 2) to one of the peripheral holes so that interstage pressure signals in a multistage gain block can be monitored.

The transfer laminates, like the exhaust and gasket laminates described in previous sections, are noncritical and have been fabricated exclusively by photochemical milling.

On the pages that follow in this section, all transfer laminates in use are pictured together with their identifying numbers and brief notes, where applicable, to describe particular common uses.

TRANSFERS

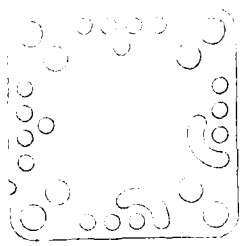
Laminate No. 5024A

Connects signal holes; used as low-resistance path to make LPA oscillators or to transform inputs and outputs.

Laminate No. 5033A

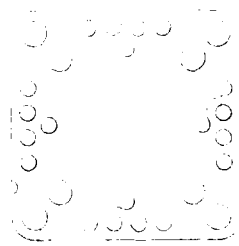
Transfers to base plate hole format (with gasket laminate No. 5034A).

Laminate No. 5035A



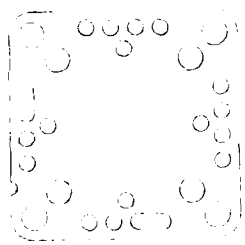
Used to bypass a section of the stack, especially to transfer input or output signals to manifold for monitoring.

Laminate No. 5037A

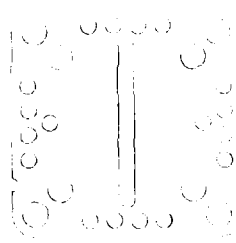


(See laminate No. 5035A.)

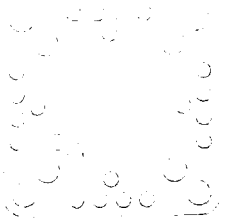
Laminate No. 5038A



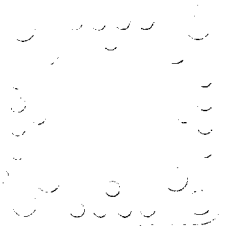
Laminate No. 5039A



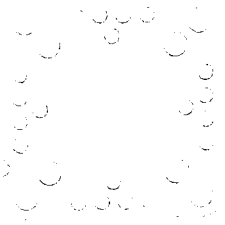
Laminate No. 5052A



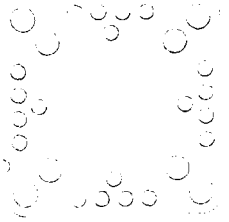
Laminate No. 5054A



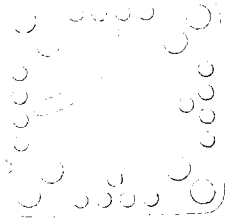
Laminate No. 5055A



Laminate No. 5056A

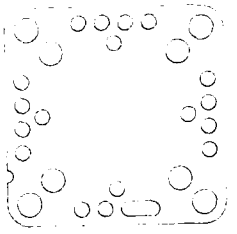


Laminate No. 5108A



Provides half the function of laminate No. 5024A.

Laminate No. 5109A

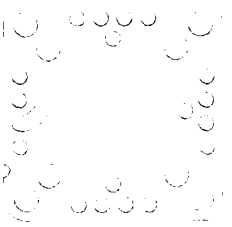


TRANSFERS

Laminate No. 5110A

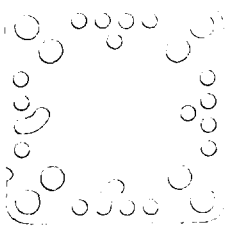
Provides half the function of laminate No. 5037A.

Laminate No. 5111A

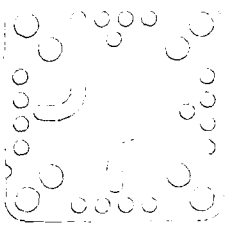


Provides half the function of laminate No. 5112A.

Laminate No. 5112A

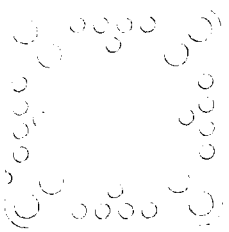


Laminate No. 5113A



(See laminate No. 5035A.)

Laminate No. 5114A

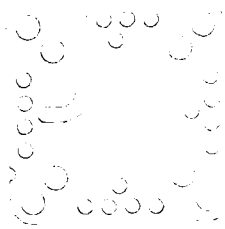


Used to connect the output of an LPA to the power nozzle of a pressure-controlled oscillator (PCO); also used to ground a signal.

Laminate No. 5115A

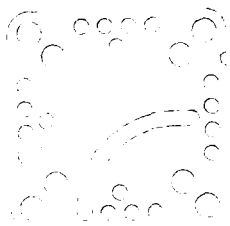
Provides half the function of laminate No. 5117A.

Laminate No. 5116A



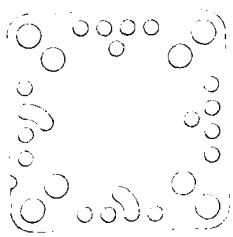
Provides half the *function of laminate* No. 5113A.

Laminate No. 5117A



(See laminate No. 5035A.)

Laminate No. 5118A

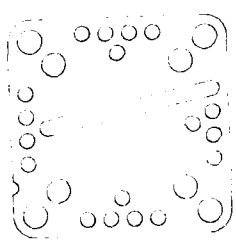


(See laminate No. 5035A.)

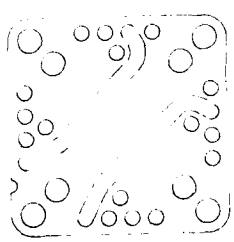
Laminate No. 5176A

(See laminate No. 5035A.)

Laminate No. 5191A

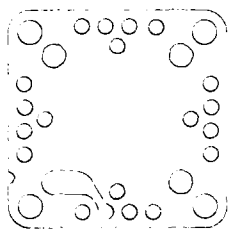


Laminate No. 5196A



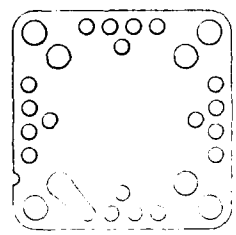
TRANSFERS

Laminate No. 5200A



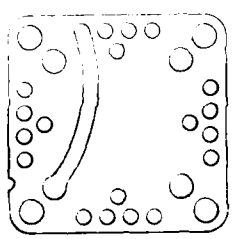
Provides means for monitoring in-stage supply pressures.

Laminate No. 5386A

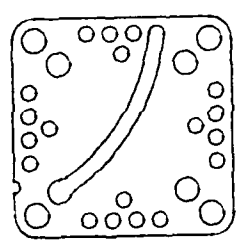


(See laminate No. 5200A.)

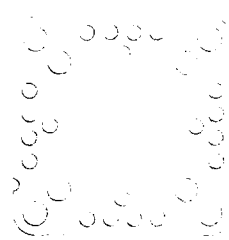
Laminate No. 5387A



Laminate No. 5388A



Laminate No. 5400A



Provides half the function of laminate No. 5176A.

NOTES

7. VENTS

The vent laminates are used in conjunction with the LPA and rectifier laminates to extract vent flow from these amplifiers. Because the vent laminates are contiguous to the amplifier laminates, they are somewhat more critical than the more common laminates (e.g., gaskets, exhausts). If there is excessive play in the four corner (bolt) holes, these laminates can shift within the stack, and this will affect the null offset characteristic of the amplifier. Null offset is the measured differential output pressure (ΔP_O) with no applied control pressure, and is a function of the supply pressure (P_S).[1] The actual shape and magnitude of the null offset curve, ΔP_O versus P_S, will depend on any asymmetries in the vent pattern itself, while too much play in the corner holes will result in variations in this curve from one run to another.

One of the vent configurations, for an LPA with b_S = 0.020 in. (0.5 mm), has been fine blanked. However, performance tests showed no measurable advantage over equivalent laminates that were photochemically milled. All other vent plates have been made exclusively by photochemical milling.

On the pages that follow in this section, all vent laminates are pictured together with their identifying numbers and notes identifying which size amplifier they are designed to be used with.

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[1] M. F. Cyser and D. J. Schaffer, *Design Guide for Laminar Flow Fluidic Amplifiers and Sensors*, Garrett Pneumatic Systems Division report under contract from Harry Diamond Laboratories, HDL CR-82-288-1 (April 1982).

VENTS

Laminate No. 5137A

Used with b_S=0.020 in. LPA.

Laminate No. 5236A

Used with b_S=0.030 in. LPA.

Laminate No. 5241A

Used with b_S=0.010 in. LPA.

Laminate No. 5339A

Used with b_S=0.015 in. LPA.

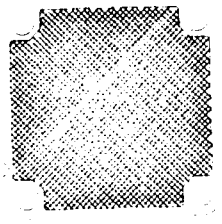
NOTES

8. MISCELLANEOUS

This section contains various specialty laminates that do not properly fit into the categories presented in the preceding sections. In the pages that follow, these specialty laminates are pictured together with their identifying numbers, descriptions of their functions, and any appropriate notes regarding their use.

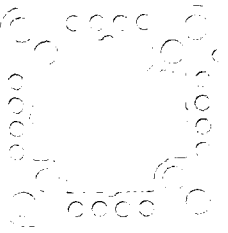
MISCELLANEOUS

Laminate No. 5005A
SCREEN



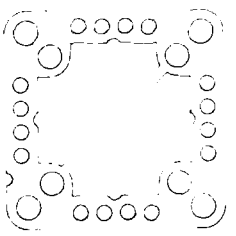
Provides last-chance filtration with 0.010-in. diameter holes; usually located in stack near base plate/manifold.

Laminate No 5023A
VOLUME



Used as in-circuit capacitor; laminate thickness is 0.010 in.

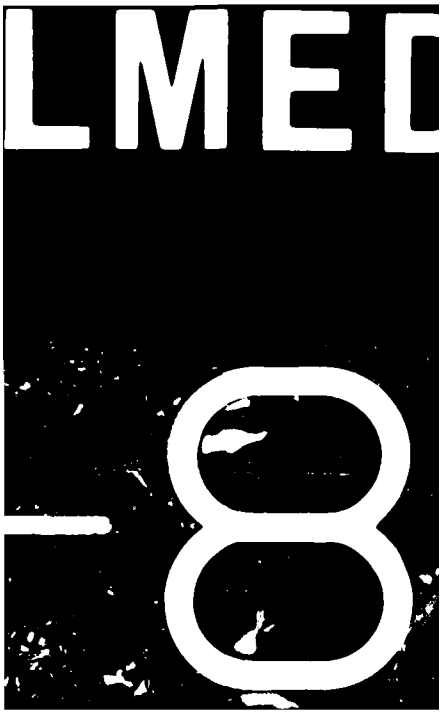
Laminate No. 5053A
VOLUME



Used as in-circuit capacitor; laminate thickness is 0.020 in.

NOTES

9. INDEX


LMED
8